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Estimating distribution of carbon stock in tropical peatland using a combination of an Empirical Peat Depth Model and GIS

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Abstract

Distribution of carbon stock below the ground of peatland of Industrial Forest Plantation in South Sumatera, Indonesia was estimated by combining an empirical peat depth model with GIS tools. The proposed peat depth model was fitted to 124 observed peat depths and showed good agreement. After that the peat depths spatial data were derived using combination of the optimized peat depth model and data elevation method (DEM) which is generated from Shuttle Radar Topography Mission (SRTM). Based on measurements of carbon content and bulk density and the estimation of peat depth distribution in study area, in total, the carbon stock was about 310 Mt.

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Keywords: peat depth model; elevation; belowground carbon stock distribution; tropical peatlands

1. Introduction

Tropical peatlands in Indonesia store huge amaount of carbon stocks as a product of high carbon content (18-60%) [1] in a relatively large area (about 170,000 km^2) [2]. It plays an important role to the global-carbon cycle which is usually associated with greenhouse gasses issues. It is estimated that greenhouse gasses especially from an increasing concentration of CO_2 in the atmosphere causes mean global surface air temperature to rise for about

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0.2 °C per decade [3]. Consequently, tropical peatlands in Indonesia become one of the main concerns in monitoring climate warming and thereby, it is necessary to quantify its carbon stocks.

Most of the peatlands in Indonesia are located in remote areas that have high spatial variability. As a result, only few studies were conducted to estimate spatial variability of carbon stock in the tropical peatlands [4, 5, 6, 7, 8]. Wahyunto *et al*. [4] estimated carbon stock using a product of peat area, depth/thickness of peat, carbon content and bulk density, after they delineated the peat distributions into land mapping units or polygons. They used average values of carbon content and bulk density according to peat maturity to calculate carbon density. In a similar way, Jainicke *et al*. [8] used SRTM and Landsat ETM+ image to delineate boundary of peat domes (i.e. peat accumulation that results in a form structure like a dome) in seven locations in Indonesia. They determined peat volume using two modeling steps: (1) generating a surface model and (2) modeling the peat thickness according to a correlation or linear function between elevation and peat depth. Subsequently, they estimated carbon stock as a product of peat dome volume, carbon content (0.58 t t^{-1}) and bulk density (0.1 t m^{-3}) which are average values for tropical peatlands in Indonesia. Therefore, objective of this study is to estimate distribution of carbon stock in belowground of peatlands of Industrial Forest Plantation in South Sumatera, Indonesia using combination of an empirical peat depth model and GIS.

2. Materials and Methods

The study was carried out in peatlands of Industrial Forest Plantation in Ogan Komering Ilir, South Sumatera, Indonesia (Insert in Fig. 1). The study area covers about 454589 Ha which lies on 2°32' S – 3°19' S and 105°13' E – 106°2' E. In total, 124 peat depth measurements with various elevations were collected (Fig 1)

An empirical model was developed for describing peat depth as a function of elevation as follow:

$$D = D_m \left[1 + \left(\frac{D_m}{D_o} - 1 \right) \exp\left(-\gamma \left[E - E_o \right] \right) \right]^{-1} \tag{1}$$

Where D is the peat depth (m) and E is the elevation (m), and D_m, D_0, E_0, γ are the empirical parameters. The optimization of those three parameters was conducted using Solver addins in MS Excell® by minimizing the root mean square error (RMSE) between the observed and modeled peat depth. Using combination of the optimized peat depth model (Eq. 2) and DEM from SRTM, the distribution of peat depth was generated.

To calculate carbon stock in belowground of soils, carbon-density equations is used [e.g., 1, 9]:

$$D_c = D D_b C 10000 \tag{2}$$

where D_c is the carbon density (t Ha^{-1}), D is the peat depth (m), D_b is the bulk density (t m^{-3}) and C is the carbon content (t t^{-1}). Average values of carbon content and bulk density in study area were reported equal to 0.567±0.108 (t t^{-1}) of 0.144± 0.013(t m^{-3}) [10]. If the peat depth is less than 0.5 m, average values carbon content of 0.351 (t t^{-1}) and bulk density of 0.340 (t m^{-3}) for peaty mineral soil/very shallow peat [4] were used.

We further compared the estimation above with carbon density from Wahyunto *et al*. [4]. Since the peatlands in South Sumetera is dominated by hemic peat maturity, with minor sapric [4], thus, average values of carbon content of 0.480 (t t^{-1}) and bulk density of 0.172 (t m^{-3}) for hemic [4] were used.

We also evaluated a linear model of Dariah *et al*. [11] for carbon density as a function of peat depth:

$$D_c = 553.4D \tag{3}$$

where D_c is the carbon density (t Ha^{-1}), and D is the peat depth (m). The total carbon stock, T_c (t) in belowground is a product of carbon density, D_c (t Ha^{-1}) and area, A (Ha):

$$T_c = D_c A \tag{4}$$

All calculations above were conducted in raster image format.

3. Results and Discussion

3.1. Peat Depth Model

As shown in Fig 1, the observed data (points) varied between 0.5 to 10 m for the peat depth and 17 m for elevation. The observed peat depth mostly distributed in a northwest part of the study area that is easy to access (Fig. 2). Moreover, we also obtained very useful data in relatively high elevation region that very difficult to access despite only 10 points of peat depth drilling. For the south part of the study area, although there is no data, the elevation of this region is relative low. Moreover, since the range of tropical peat depth in Indonesia vary between 0.5 to 10 m [5, 6, 7], the range of observed peat depth in this study seem enough to represent variation of peat depths in the study area.

The empirical model (Eq. 1) as well as linear regression was fitted to the peat depth data. The observed (closed circles) and fitted (solid lines) peat depth were depicted in Fig 2. It is obvious that the empirical peat depth model could describe the observed excellently with $R^2 = 0.93$ and RMSE = 0.58. It is slightly better than a linear regression with $R^2 = 0.90$ and RMSE = 0.69. The optimized parameters were $D_0 = 0.50991$ m, $D_m = 9.78145$ m, $\gamma = 0.79918$ m^{-1}, and $E_0 = 10$ m. It can be interpreted that D_m represents maximum peat depth that has resulted from the data set. Note that this model will go toward infinity to D_m with increasing the elevation. The D_0 corresponds to E_0 which is minimum elevation in the data set and γ controls the slope of the model. The shape of curve was similar to S letter.

3.2. Distribution of Peat Depth

Figure 1 also shows distribution of peat depth derived using the optimized peat depth model (Eq. 1) as a function of elevation (DEM) from SRTM data. Table 1 shows area and volume of peatlands in the study area according to peat depth classifications [4]. Most of study area was dominated by very shallow peat (<0.5 m) about 338469 Ha or 75 %, then very deep peat was about 44671 Ha or 10 %, while the area of deep peat (2-3 m), moderate (1-2 m) and shallow (0.5-1 m) peatland classes were less than 10%. In total, the volume of peatlands was 3684 Mm^3. Mostly; peat was located in very deep class about 2489 Mm^3 or 67.5% of total volume and then followed by deep peat, moderate and shallow peatland classes.

SRTM data represents a Digital Surface Model (DSM) because SRTM C-band sensor does not penetrate dense vegetation cover [8]. As a result, SRTM image accounts vegetation height. Therefore, to obtain the surface elevation of surface, a correction factor is needed. Since we did not give the correction factor in this study, error of peat depth estimation can raise from this factor. However, since the peat swamp forest of Telukpulai peat dome was completely removed before SRTM acquisition in February 2000 [8], the SRTM data in the study area might be assumed as a Digital Terrain Model (DTM) which no need the correction factor for compensating the vegetation height.

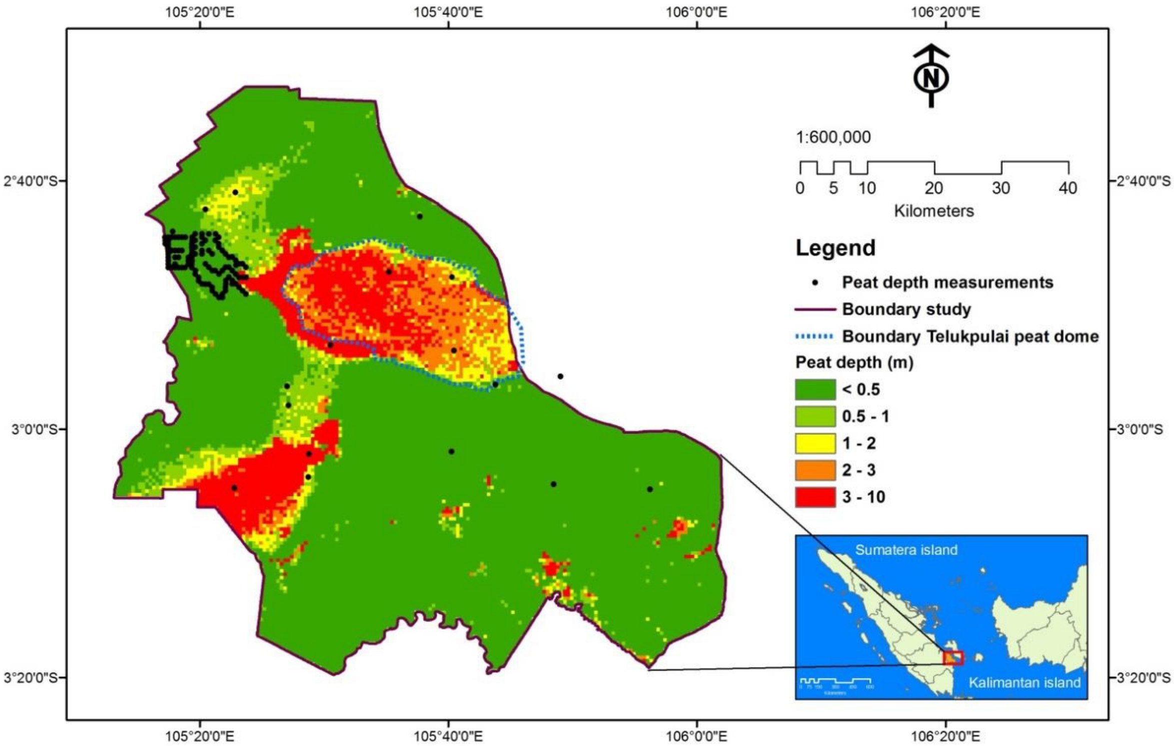

Fig. 1. Point measurementsof peat depth, peat depth distribution based on the empirical model and boundary Telukpulai peat dome

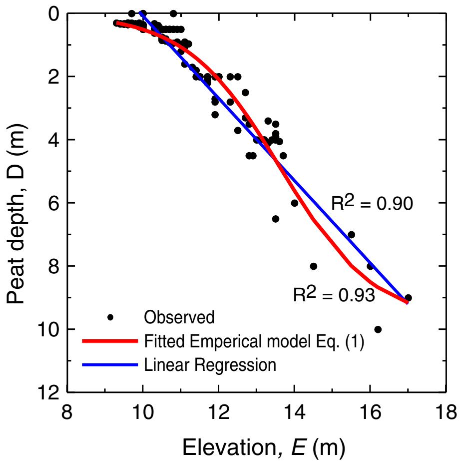

Fig. 2. Observed (closed circles) and fitted peat depth using the empirical peat depth model, Eq. (1) (red lines) and linear regression (blue lines)

Table 1. Distribution of peat depth, volume and comparison of total carbon stock based on carbon density calculated from measurements in study area, Wahyunto *et al.* [4] and Dariah *et al.* [11]

Class	Peat depth	Area		Volume		Total carbon stock		
						Carbon density from		
						Study area	Wahyunto *et al*. [4]	Dariah *et al*. [11]
	[m]	[Ha]	[%]	[Mm^3]	[%]	------------------[Mt]------------------		
Very shallow	< 0.5	338469	75	229	6	27	27	13
Shallow	0.5-1	27280	6	166	5	14	14	9
Moderate	2-Jan	19645	4	249	7	20	21	14
Deep	3-Feb	24523	5	551	15	45	45	3.2.1. 31
Very deep	3.2.2. > 3 (3-10)	3.2.3. 44671	10	3.2.4. 2489	68	3.2.5. 203	3.2.6. 205	3.2.7. 138
Total		454589	100	3684	100	310	312	204

Table 2. Comparison of area, volume and carbon stocks in Telukpulai peat dome

	Area	Volume	Mean peat depth	Total carbon stock
	[Ha]	[Mm^3]	[m]	[Mt]
This study (carbon density from study area)	50000	1500	3.0	107
Jainicke *et al.* [8]	47000	2250	4.8	130

3.3. Distribution of Carbon Stocks

Table 1 summarizes the distribution of total carbon stocks in peat depth classification. The distribution of total carbon stocks based on carbon density from study area was almost identical with carbon stocks based on carbon density from Wahyunto *et al*. [4]. While carbon stocks based on carbon density from Dariah *et al.* [11] showed lower values. It can be explained that the weight of organic carbon per unit volume of soil in the study area ($C_v = D_b$ x C = 0.567 x 0.144 = 0.082 t m^{-3}) was almost same with that in Wahyunto *et al*. [4] (0.480 x 0.171 = 0.082 t m^{-3}), whereas that in Dariah *et al.* [11] was lower ($C_v = D_c / 10000D$ = 553.4/10000 = 0.055 t m^{-3}; see Eq. 3) than the result from our study. Therefore, application of the linear regression of Dariah *et al*. [11] in the study area will lead to underestimation.

According to carbon density from study area, the total carbon was stored mainly in very deep peat which was 203 Mt or 66% of the total. In the deep peatlands, total carbon stocks were about 45 Mt or 14% of the total and the rest were distributed in moderate (20 Mt or 7%) and shallow (14 Mt or 4%) and very shallow peatlands (27 Mt or 27%). In total, carbon stock in belowground of peatlands in the study area was approximately 310 Mt.

3.4. Carbon stocks in Telukpulai Peat Dome

We further compared the results from this study (based on carbon density in study area) with Jainicke *et al*. [8] results for the area, volume and total carbon stocks in Telukpulai peat dome as presented in Table 2. Boundary of Telukpulai peat dome was shown by blue dash lines in Fig. 1. By comparison, our estimation for the area was 50000 Ha which was similar to Jainicke *et al.* [8] of 47000 Ha. On the other hand, our estimation for the volume (1500 Mm^3) was significantly lower than Jainicke *et al*. [8] of 2250 Mm^3 indicating different peat depth models. As a result, the mean peat depth from this study (3 m) was lower than that in Jainicke *et al.* [8] about 4.8 m. Note that Jainicke *et al*. [8] used a linear peat depth model (i.e. a correlation between peat surface or elevation and peat depth) where the peat depth always increases to infinity value with increasing elevation, whereas our peat depth model will go toward infinity to D_m parameter value. Since the elevation of Telukpulai dome is relatively high, thus their model resulted in deeper peat depth than us. Moreover, there is no the observed peat depth data in Jainicke *et al*. [8] for Telukpulai, while it were available in this study albeit only four point measurements. Therefore, our estimation on peat dome volume for Telukpulai might be more reliable than their results.

As shown in Table 2, estimation of total carbon stock in Telukpulai peat dome in this study was about 107 Mt which was similar to Jainicke *et al*. [8] of 130 Mt although our estimation on peat dome volume was a half from their estimation. It occurs because the weight of organic carbon per unit volume of soil in this study ($C_v = D_b$ x C = 0.567 x 0.144 = 0.082 t m^{-3}) was larger than that in Jainicke *et al*. [8] (0.580 x 0.100 = 0.058 t m^{-3}). It showed that large weight of organic carbon per unit volume of soil was compensated by low volume of peat dome in this study. It is suggested that determination of carbon content as well as bulk density of peat also strongly affect on calculation of carbon stock in peatlands. Since carbon stock is a product of three factors: carbon content, bulk density, and peat depth, those all three factors will give same role on the accuracy of estimation for the carbon stocks.

4. Conclusions

The empirical peat depth as a function of elevation model could describe the observed peat depth-elevation data in peatland of Industrial Forest Plantation in South Sumatera, Indonesia excellently. Based on the optimized empirical peat depth model and DEM, the peat depth distribution was generated. The distribution of total carbon stock belowground in peatland could be determined using a product of the peat depth distribution, area and carbon density. According to measurements of carbon content and bulk density and estimation peat depth distribution in study area, in total, the carbon stock in the study area was about 310 Mt. Because of limitation of data sets, validation of the estimation is still required in the future.

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